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The effect of microscale spatial variability of wind on estimation of technical and economic wind potential

Olexandr Balyk, Jake Badger, and Kenneth Karlsson

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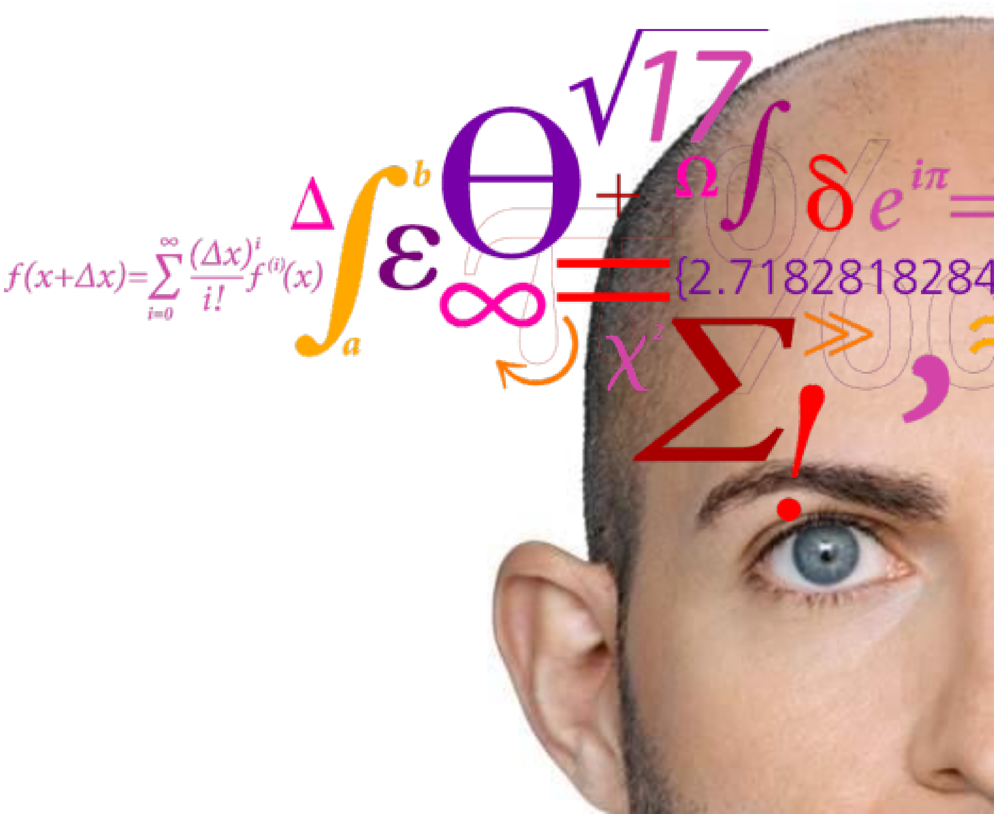


Background

Global wind potentials

- Based on coarse resolution wind speed data
- Less complex estimation techniques
- Disregard small scale variability of wind

Local wind potentials

- High resolution measured data
- More complex estimation techniques
- Estimates are not available for every country
- Not uniform assumptions across studies

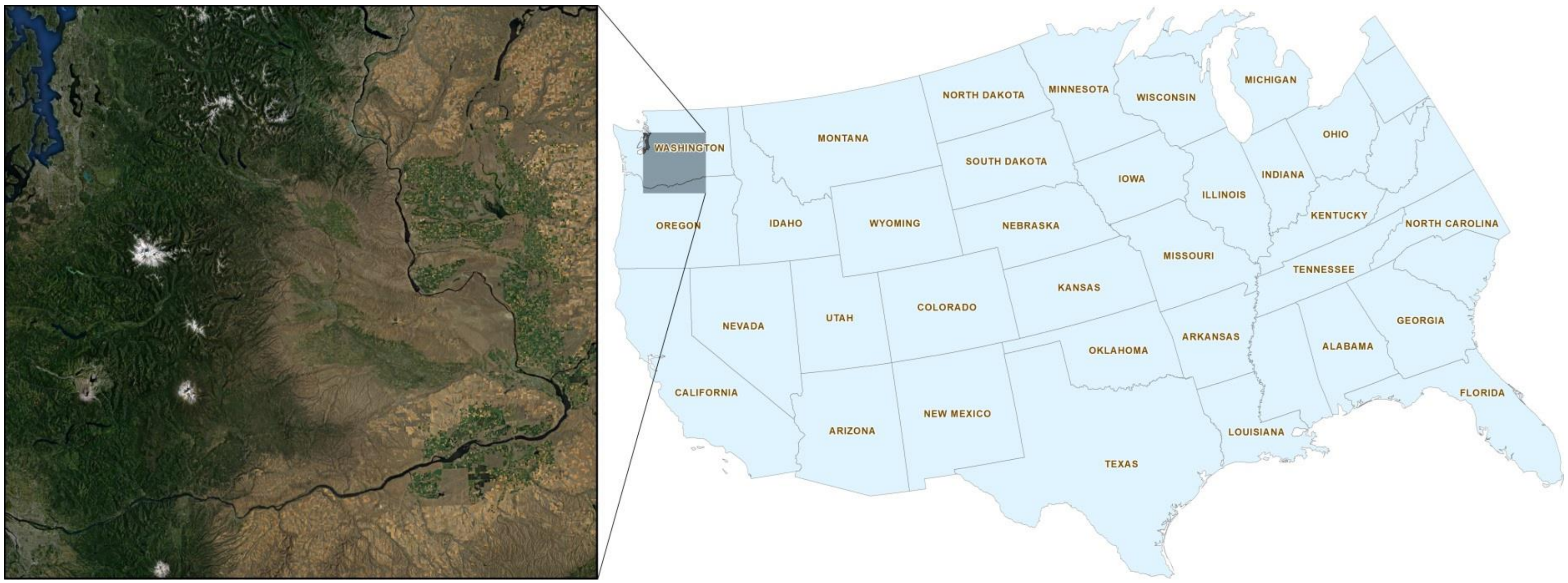
Global Wind Atlas project is aiming at producing global microscale wind climate data from existing mesoscale datasets by means of statistical downscaling.

Note: mesoscale: 3-100 km, microscale: < 3 km

Aim

- Demonstrate a new methodology for estimating wind energy potential using GWA data
- Provide an indication of how high resolution wind data influences the estimated wind energy potential

Test Area

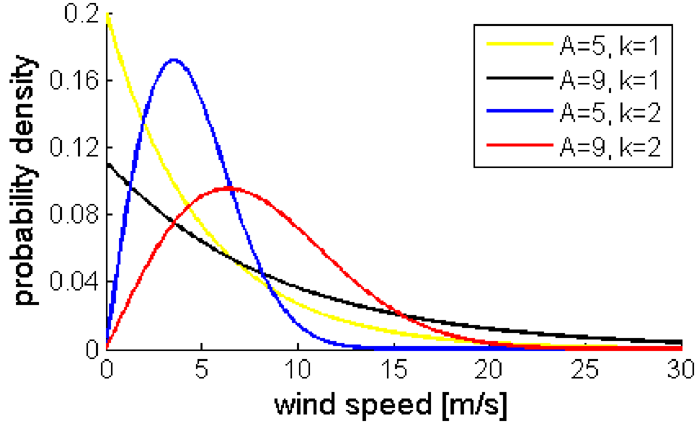


- Mostly located in Washington State
- Characterised by complex terrain
- Area size 310x300 km

Methodology – Input Data

Wind climate data (DTU Wind)

- Weibull parameter k by sector
- Weibull parameter A by sector
- Sector frequency
- Spatial resolution - 250 m
- Height - 100 m a. g. l.



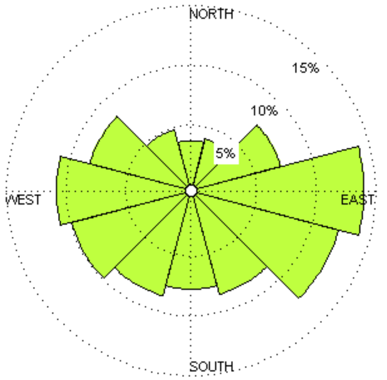
$$f(u) = \begin{cases} \frac{k}{A}\left(\frac{u}{A}\right)^{k-1} e^{-(u/A)^k} & u \geq 0 \\ 0 & u < 0 \end{cases}$$

Wind turbine data

- Vestas V90 3MW power curve

Area exclusion data

- Protected areas of Pacific States



Methodology – Gross Technical Potential

1) Weibull cumulative distribution function:

$$F(u,s) = 1 - Exp(-(u/A(s))^{k(s)})$$

2) Probability of a wind speed interval (i.e. $1\ m/s$ interval)

$$p([u_1, u_2], s) = F(u_2, s) - F(u_1, s)$$

3) Mean power generation by sector:

$$\overline{TP(s)} = \sum p([u_1, u_2], s) \times TP((u_1 + u_2)/2)$$

4) Omnidirectional mean power generation:

$$\overline{TP} = \sum f(s) \times \overline{TP(s)}$$

5) Annual energy production:

$$AEP = \overline{TP} \times 8766$$

u – wind speed, m/s
s – sector
f – frequency
p – probability
TP – turbine output, MW

Methodology – Area Exclusion

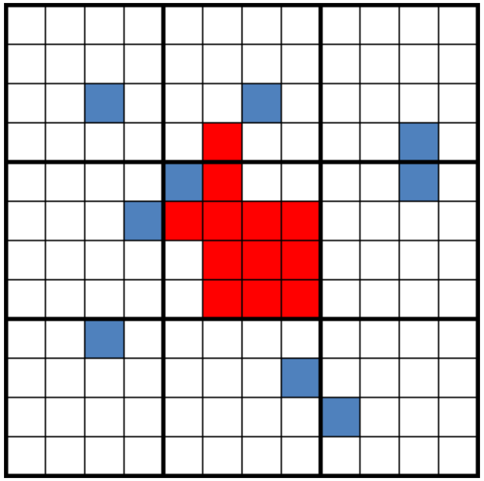
Some areas are not suitable for wind power development due to e.g., their physical characteristic or management practice.

We use GIS to exclude (based on IUCN classification):

- Strict nature reserves
- Wilderness areas
- National parks
- Natural monuments
- Habitat/species management areas
- Protected landscape/seascape areas
- Managed resource protected areas

Other areas are necessary to exclude to estimate an actual potential.

Methodology - Methods for estimating net wind power potential



Maximum approach

Maximum AEP in a 4x4 grid cell array

Average approach

Average AEP in a 4x4 grid cell array

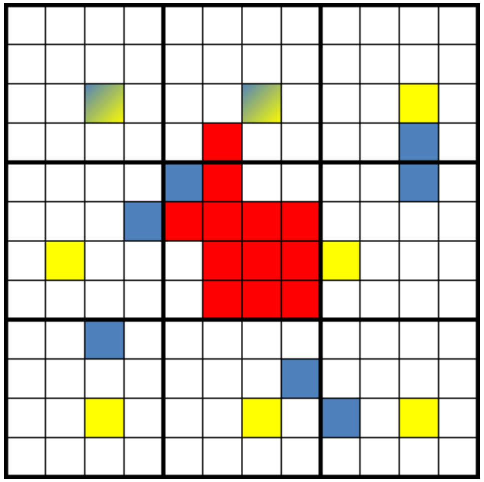
Binary integer programming approach

$$\sum_{i=1}^{m}\sum_{j=1}^{n} x_{ij} \times AEP_{ij} \rightarrow max$$

subject to:

$$\begin{cases} \displaystyle\sum_{i=I}^{I+G-1}\ \sum_{j=J}^{J+G-1} x_{ij} \leq 1\ \forall\ I \in \{1,2,3,\dots,m-G+1\}, \forall\ J \in \{1,2,3,\dots,n-G+1\} \\ x_{ij} \in \{0,1\}\ \forall\ i \in \{1,2,3,\dots,m\}, \forall\ j \in \{1,2,3,\dots,n\} \end{cases}$$

Methodology - Methods for estimating net wind power potential



Maximum approach

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Methodology – Other Aspects

Economic potential

Many factors influence costs of project development e.g., distance to grid, access to roads etc.

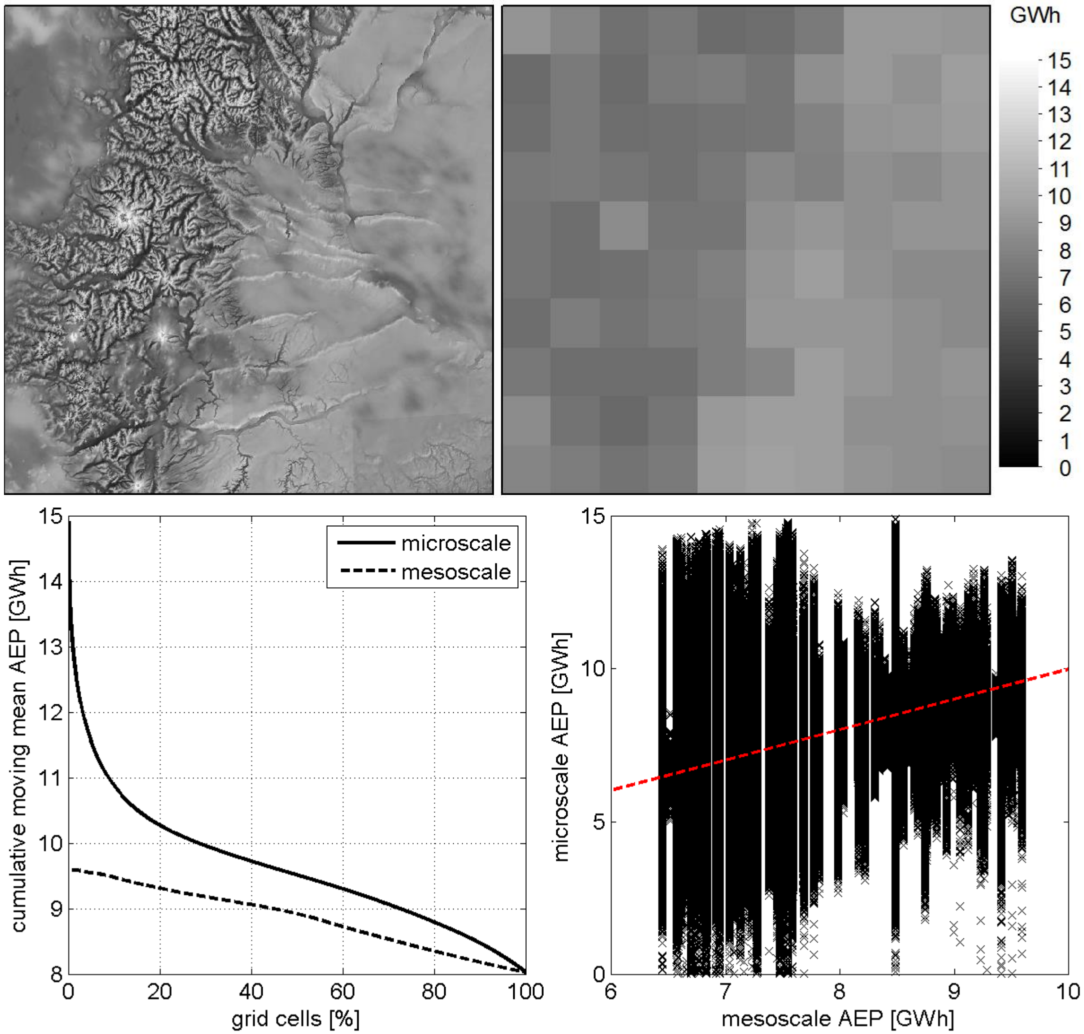
We exclude grid cells with CF<.35 to simplify the comparison

Comparison with mesoscale data

Mesoscale data for the same area was not available

Used simulated mesoscale data, produced by averaging microscale AEP values with grid cell spacing of 30 km

Results - AEP

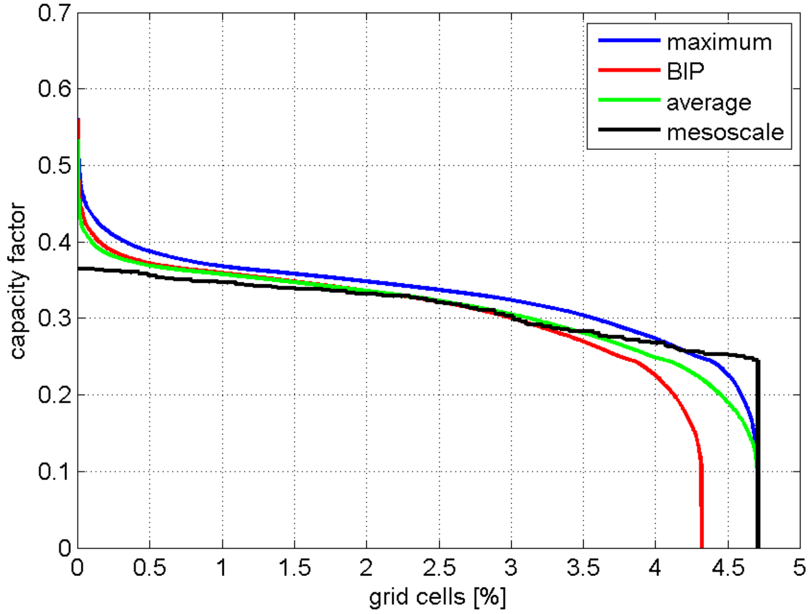


- Microscale variation 0 to 14.9 GWh (left)
- Mesoscale variation 6.4 to 9.6 GWh (right)

- 20% mean AEP difference for the top 5% grid cells
- 14% mean AEP difference for the top 10% grid cells

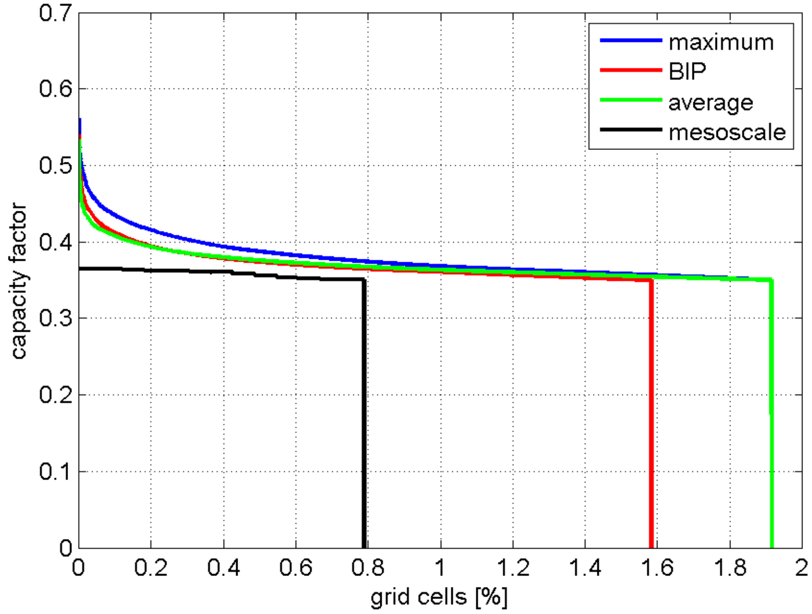
Results – Net Wind Potential

Technical potential



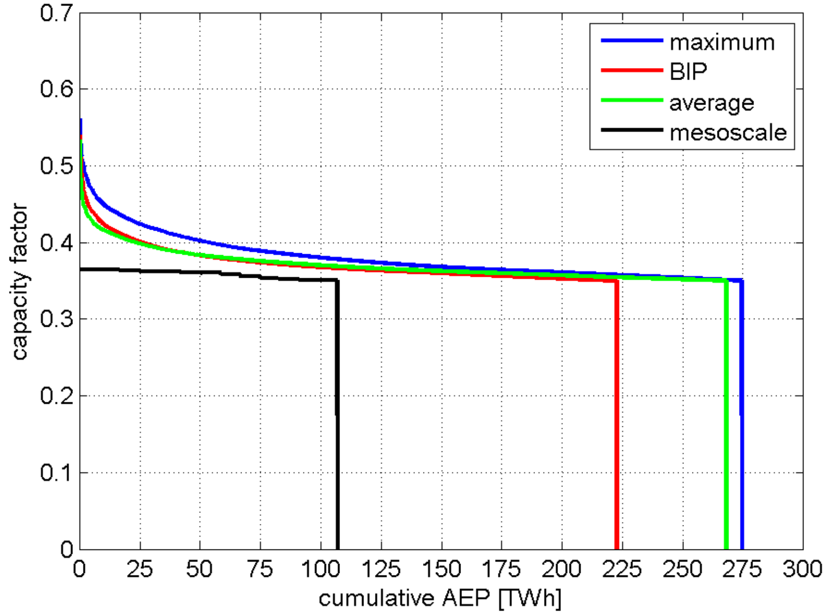
Low variation in capacity factors from mesoscale data

Economic potential



Potential is at least twice as high with microscale data

Results – Economic Potential



Mesoscale potential is just enough to cover power demand of Washington State (i.e. roughly 100 TWh)

BIP approach results in 45-51 TWh lower potential than other microscale approaches

Cumulative AEP, TWh	Mesoscale, GW	Maximum, GW	Average, GW	BIP, GW
5	1.6	1.2	1.3	1.2
10	3.1	2.4	2.6	2.6
20	6.3	5.0	5.4	5.3
50	15.7	13.3	14.2	14.0
100	31.8	27.9	29.3	29.3
200	n/a	58.8	60.8	61.0

Capacity needs to produce target AEP are higher for the mesoscale data

Conclusions

- Overall potential is higher when using microscale data
- More than doubling of economic potential when going from mesoscale resolution to microscale
- Three approaches: BIP is conservative, maximum approach is optimistic and the average approach combines lower wake uncertainty and simplicity
- Implications for global energy system modelling:
  - More realistic potential
  - Higher competitiveness of wind power
  - Increased climate change mitigation potential

Thank you for attention!